A SOLID BLOCK IMAGE SLICER FOR NGST`

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1. Optical layout

Image slicers of the type that can sharply focus the sky onto the slit of a spectrograph require three powered optical elements in the light path for each slice. In the reflecting design outlined here, the first mirror is in the form of a reflecting slit located where the sky is focused by the telescope. This tilted, concave slit-mirror focuses the primary mirror (pupil) of the telescope onto a concave re-imaging mirror, which in turn focuses the sky (the slit mirror segment) onto a field lens where the slit of the spectrograph is located. Each slice of the sky requires a set of these micro-optics, as shown in Figure 1a where the slit is perpendicular to the paper and in Figure 1b which is a side view where the slit is in the plane of the paper. The slit mirrors are located side-by-side (Fig 1a) but the images of the slit mirrors are aligned end-to-end (Fig 1b) along the slit of the spectrograph by the tilted re-imaging mirrors. Thus the light from a two-dimensional object or field of stars is re-arranged so that it can enter the long, narrow slit of a spectrograph. Eleven of the 22 slices are shown in the figures. The optical prescription is available in both CodeV and Zemax formats.

The design shown in Figures 1 a, b uses back surface mirrors for the first two optical elements in a path, and a lens for the third. These optical surfaces could either be cemented or etched onto the outside of a single block of glass. The entrance surface of the slicer is above the focal surface of the telescope, and the slit mirrors are below the surface. Two prisms with total internal reflection are used to bend the beam so that the exit slit of the slicer is on the focal surface of the telescope. Thus no changes would be needed to either the telescope focus or to the collimator of the following spectrograph when the slicer is inserted. However, these prisms could be eliminated if the spectrograph were never used with the bare telescope, or if it were designed for slits at different axial distances from the bare telescope focus. (For example, if the slicer were to be used with a spectrograph which was also to be fed by slits illuminated by fibers with a minimum of bending of the fiber, the exit from the fibers might be below the telescope focal surface.) In that case, it can be seen in the drawings that if the two prisms were removed then the exit slit of the slicer would lie beside the rectangular set of entrance slit mirrors. This would have the advantages of reducing the width of the slicer and decreasing the cost (but it would not increase the transmission because the prisms are totally internally reflecting and thus have 100% reflectivity).

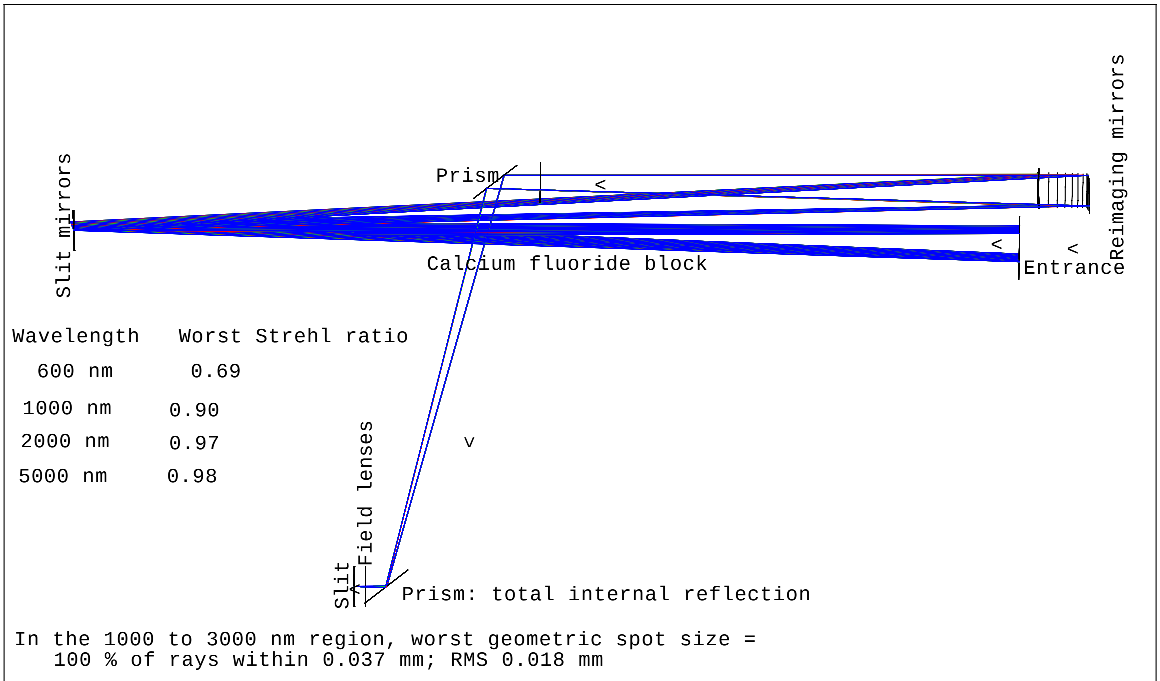

Fig 1a. Plan vew: slit perpendicular to plane of paper.

NGST IS, slices 12 to 22	Positions: 1-11EHR 19-Jul-99

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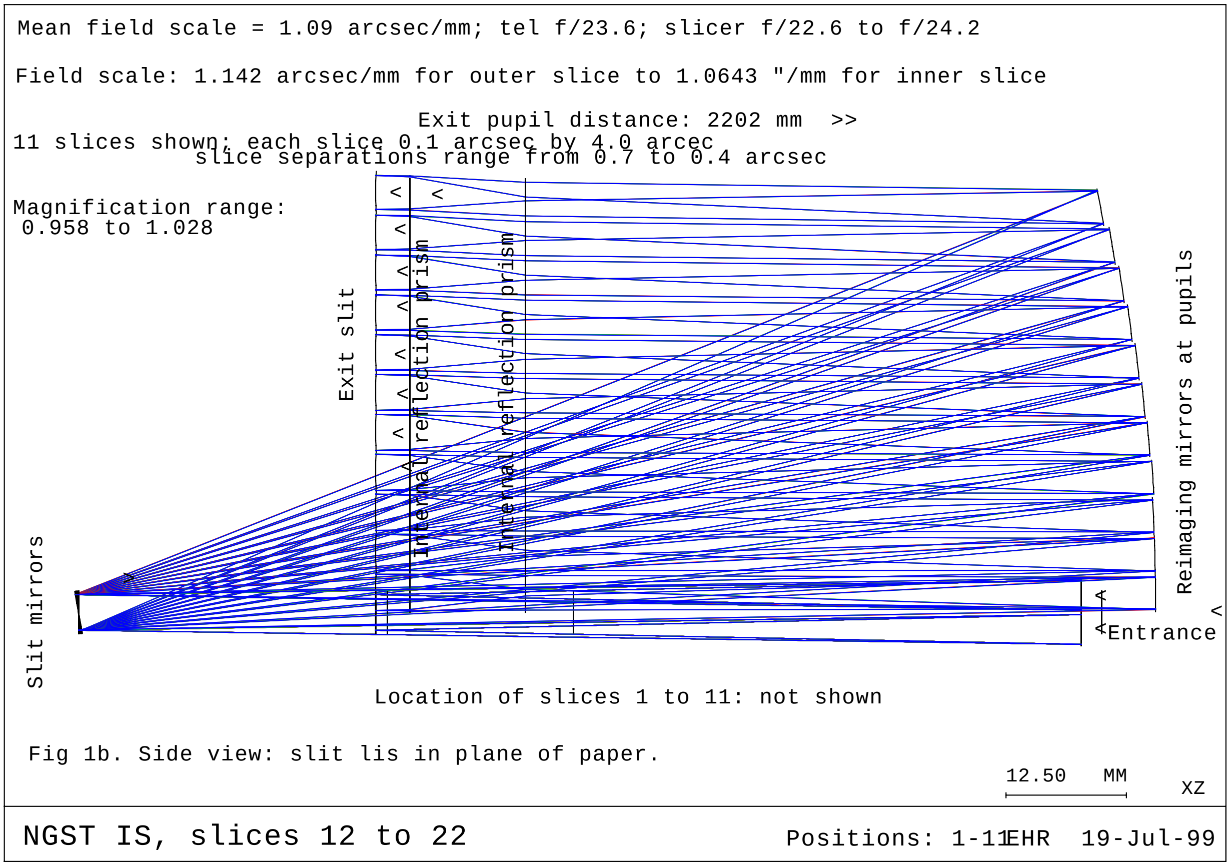

Fig 1b. Side view: slit lis in plane of paper.

The slit mirrors and the field lenses have spherical surfaces but the re-imaging mirrors are toroidal, resulting in a spatial resolution within the slices which is diffraction limited at 1 micron. For an 8 meter telescope the FWHM (Full Width at Half Maximum) of the Airy disc is 0.06 arcsec at 2 microns. That is the wavelength where the telescope is specified to be diffraction limited, i.e., where the Strehl ratio of the images is better than 0.8 (the Strehl ratio is the ratio of the intensity of the core of the diffraction pattern (Airy disc) compared with that of a perfect optical system). The mirrors, which are metal coatings deposited on the outside of the glass, are illuminated by light inside the glass, thus the outside of the mirrors can be sealed from possible contact with contaminants. To summarize, the image slicer design has only two air/glass surfaces and only two internal reflections are required. It can be fabricated from a single solid block and hence is inherently very stable.

2) Location of Exit Pupil

Most telescopes are designed to be telecentric but the design given in the NGST “Yardstick” design is not. The location of the exit pupil of the image slicer can be adjusted by changing the tilts of the slit mirrors and the location and tilts of the re-imaging mirrors. In the design shown, the exit pupil is made to be at the location of the exit pupil of the "Yardstick" NGST, which is 2.2 meters before the focal surface (but which will probably be changed). The slicer is versatile in the location of the exit pupil which thus can be matched to an optimum entrance pupil location for a given spectrograph design.

3) Field of View and Range of Field Scales

Each slit mirror is 4 arcseconds long and 0.1 arcsec wide. Thus the 22 mirrors have a total aperture of 4 by 2.2 arcsec on the sky which is transformed by the re-imaging mirrors to 88 arcsec by 0.1 arcsec at the slit of the spectrograph. To prevent information from the ends of individual slices from overlapping, a small (0.5 arcsec) gap was intentionally introduced between each slice when it is projected onto the output slit. Hence the total length of the slit in the notional design is 99 arcsec or 91 mm.

The field scale at the focus of the F/24 NGST telescope is 1.09 arcsec/mm which is also the mean scale at the output of the image slicer. However, the scales in individual slices in our design range from 1.14 for the outermost slices to 1.06 arcsec/mm for the two innermost slices. This is because of the differences in light path from the slit-mirror to the re-imaging mirror to the output slit for the various slices. This change of field scale would not significantly affect the scientific performance of the slicer and so was judged acceptable.

The variation of scale depends on the angle and so it increases if the total slit length were to be increased, i.e., if additional slices are added or if the length of each slice is increased. If required, the change in scale could be reduced by segmenting the internally reflecting folding prisms and repositioning the individual prisms to increase the distance from the outer re-imaging mirrors to the slit to equal the distance from the inner ones resulting in unit magnification for all slices. A design incorporating this refinement was done as an option for an image slicer with longer slit lengths for the GMOS spectrograph of the Gemini telescope. However, to reiterate, we believe this complication is not necessary for the NGST image slicer.

4) Sensitivity to Temperature Change

The solid block design has several advantages, especially for an image slicer that will be subjected to a large change of temperature.

Because the structure is made of the same material as the optical surfaces, thermal expansion or contraction would apply equally to the curvature of the surfaces and to their separations, thus the mirrors would stay exactly in focus. The lenses, however, would not remain exactly in focus because the index of refraction does not decrease as much as the lens curvature. In our design, however, the defocus of the exit pupil is minimal and could be eliminated altogether at operating temperature by specifying less curvature at room temperature when the lens is made so that it is optimal when the lens is cooled. The focal length of the lens is not critical because it serves simply as a field lens.

The variation of the index of refraction, N, of the glass with temperature will change the apparent location of the slit mirrors as seen from the telescope. However, the temperature-induced change of N is ten times smaller than the change of N over the wide wavelength range of 1 to 5 microns. For a drop in temperature of 238 degrees, the wavelength-induced change in N is 0.03 compared with the temperature induced change, of 0.0025, given dN/dT = -10.6e-6/degC. The thermal contraction of the CaF in the 104 mm between the flat entrance surface and the slit-mirrors is 0.47 mm, the coefficient being 18.85e-6/deg. However, the decrease in N multiplied by that distance is 0.26 mm, thus the net defocus is only 0.2 mm. The resulting image blur is this number divided by the focal ratio in the CaF which is F/34 and so will be 6 microns, i.e., much smaller than the slit width of 100 microns. Lthough not necessary, mounting the slicer at the best focus for 35K could compensate for this small defocus effect. Alternatively, the telescope focus could be changed by 0.2 mm - it would probably need refocusing anyway because of the much larger focal change by contraction of the telescope structure.

In summary, the focus of the image slicer is insensitive to temperature changes.

5) Light Loss

There are only two air-to-glass (or vacuum-to-glass) surfaces in the light path, plus two metal reflections. If calcium fluoride, whose index of refraction at 2 microns, N=1.424, is used as the material, the loss by reflection at the refractive surfaces would be 3% per surface. This is less than for most glass types, and could be reduced even more with an anti-reflection coating of magnesium fluoride. Depending on wavelength, the resulting residual reflectivity would vary from 2.0% to 2.6%. Because the index of refraction of calcium fluoride is low, differing by only 0.05 from the magnesium fluoride coating, there is little reduction in reflection loss by an anti-reflection coating, but it would provide additional protection. The reflectivity of the silver or gold mirrors would be about 98% per surface, thus the total light loss at optical surfaces would be less than 10%.

6) Consequences of Choice of Glass Type

Other glasses were explored as alternatives to our initial choice of CaF. If a high index infrared transmitting glass such as Zinc Sulfide (whose N=2.26 at 2 microns) is used instead, the reflection loss at a bare air/glass surface is high: 15% per surface, or a 28% loss from the two surfaces. In this case, a MgF anti-reflection coating reduces the reflection by a large amount, to 1% at one selected wavelength where the reflections from the MgF and ZnS subtract. This is smaller than for coated CaF. However, a disadvantage of ZnS is that the reflectivity rises at other wavelengths, reaching 8.6% per surface, or 16% for the two surfaces. Thus, for a high index material an anti-reflection coating is essential, but the average reflection loss would still be higher than if CaF is used. Another good IR transmitting material is Zinc Selenide, but its N is even higher: 2.446 at 2 microns. The bare reflection loss per surface is 18%, thus 32% for the two surfaces. With a MgF anti-reflection coated at 2 microns the loss is reduced to 1.9% per surface, thus 3.8% for the two surfaces, but it rises to 10.5% at other wavelengths in the region, thus to 19.8% for the two surfaces.

The slicer in Figures 1a,b is designed for CaF but, if changed to another glass type with a higher index of refraction, it is necessary to change only the distance from the entrance surface to the slit mirrors. An example is shown in Figure 2. The re-imaging mirrors can be smaller with the high N glass because the internal focal ratio is longer: 24*2.26 = F/54, cf. F/34 with CaF. This simple re-design was also done for other IR transmitting materials: silicon, barium fluoride and zinc sulfide. All deliver diffraction limited image quality.

A potential advantage of the higher index glasses, such as ZnSe, is that the angle of incidence onto the internally reflecting prisms can be increased without losing total internal reflection. Thus the first prism can be moved much further from the re-imaging mirrors. Consequently, the lateral distance to the exit slit can be decreased in proportion, and hence the image slicer can be narrower than for the CaF version, and block less of the focal surface, thus, for example, allowing fiber pickups to be positioned closer to the mage slicer. Overall, however, CaF appears to be the best material for the NGST image slicer.

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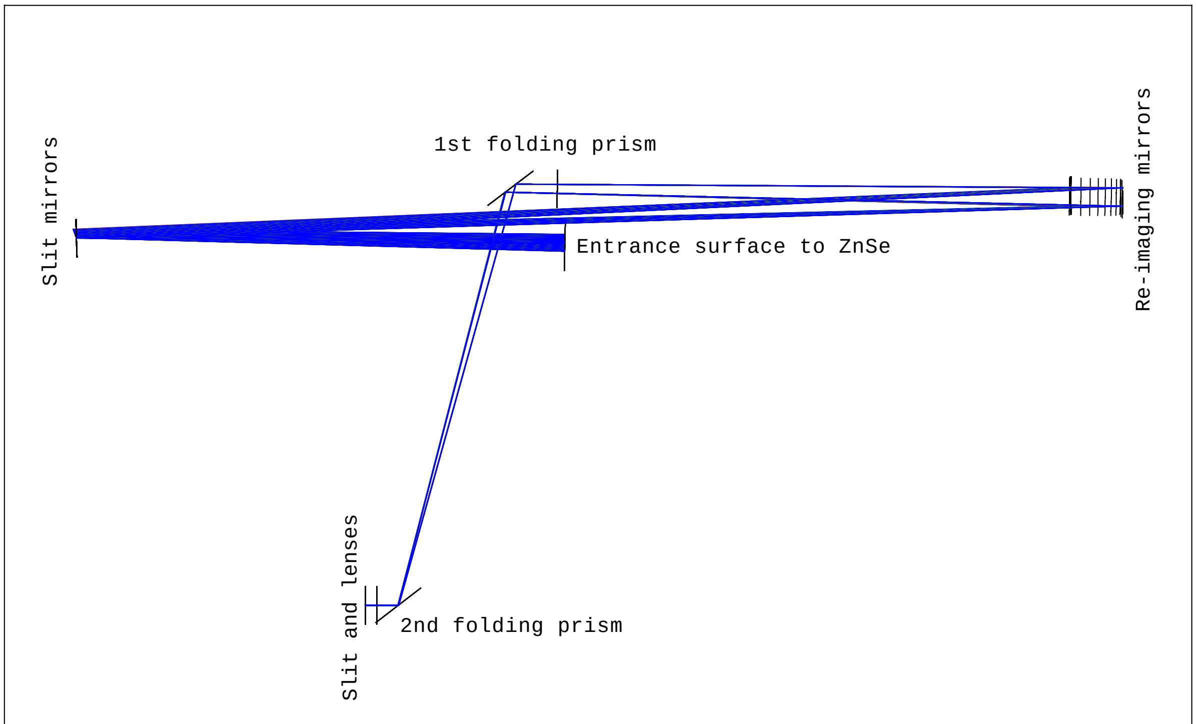

Fig 2. Plan view if CaF replaced with Zinc Selenide

12.50 MM

NGST IS, ZNSE, 11 of 22 slices   Positions: 1-11EHR   19-Aug-99